Jet Propulsion Laboratory
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Overview of the ASPIRE Targeting System and Flight Results

42nd AAS Guidance and Control Conference

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ASPIRE

The ASPIRE Project

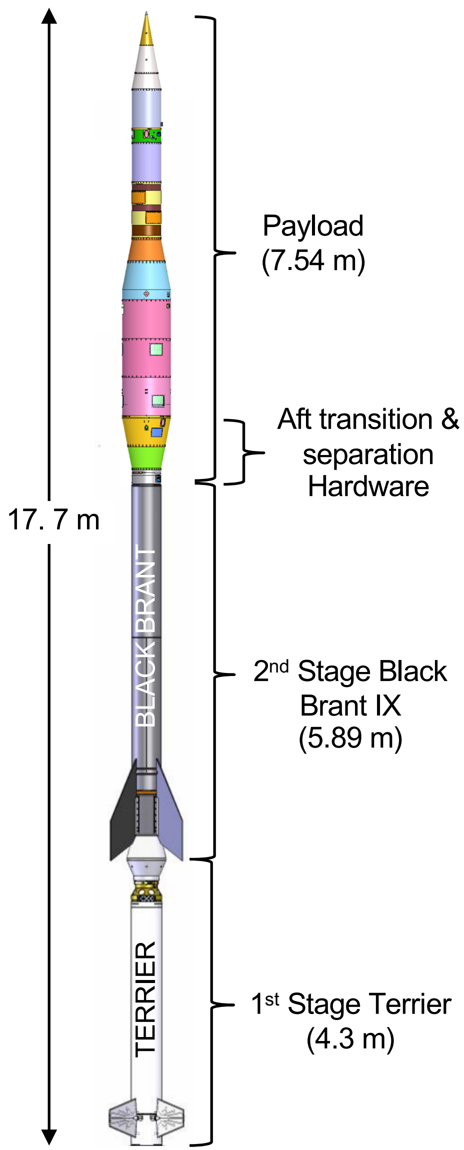
ASPIRE

- **A**dvanced **S**upersonic **P**arachute **I**nflation **R**esearch **E**xperiments Project Objectives:
  - Develop testing capability for supersonic parachutes at Mars-relevant conditions.
  - Deliver 21.5m parachutes to low-density, supersonic conditions on a sounding rocket test platform
  - Acquire data sufficient to characterize flight environment, loads, and performance
- Initial flights focused on testing candidate designs for Mars2020:
  - Built-to-print Mars Science Laboratory (MSL) DGB (disk-gap-band)
  - Strengthened version of MSL DGB (identical geometry, stronger materials)

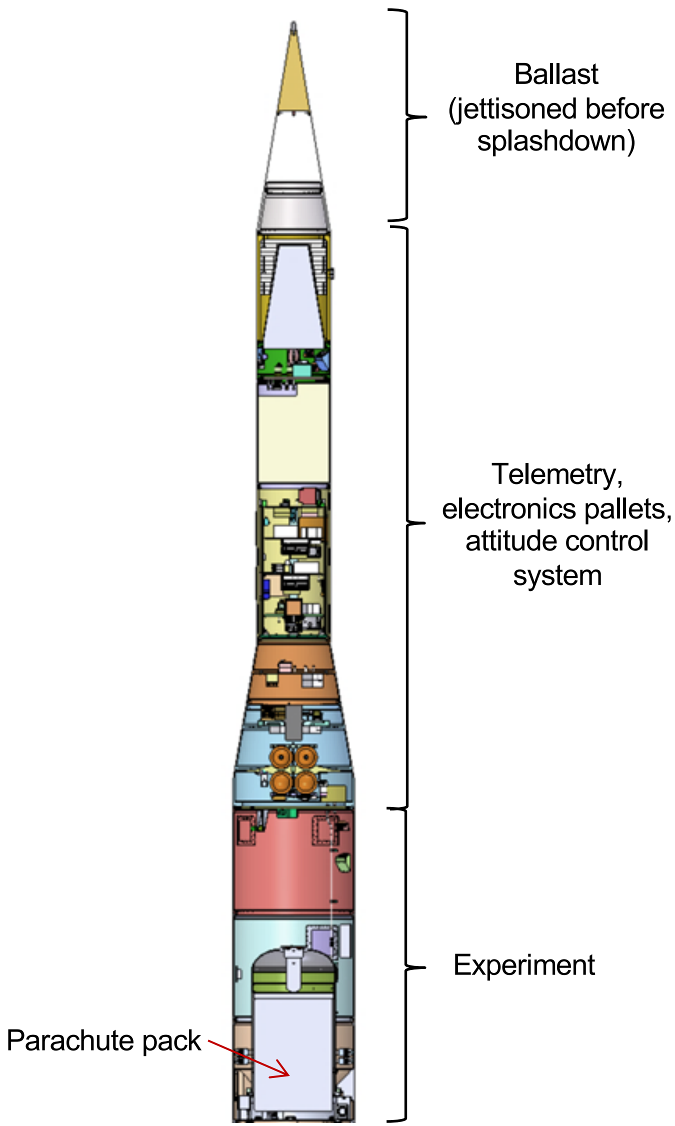
	Parachute	Load	Purpose	Test Date
SR01	MSL built-to-print	35 klbf (MSL @ Mars)	Test architecture shakeout. Ensure test approach doesn't introduce new parameters.	Oct. 4th, 2017
SR02	Strengthened	47 klbf	Incremental strength test of new design.	Mar. 31st, 2018
SR03	Strengthened	70 klbf	Strength test of new design	Sept. 7th, 2018

Test Architecture

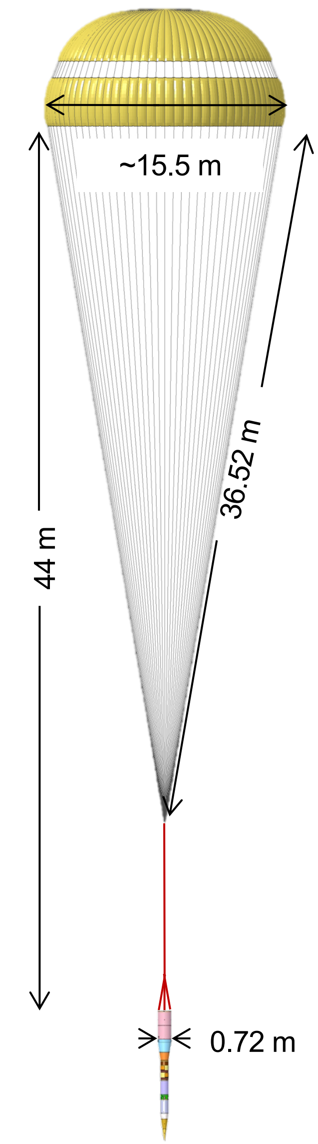
Launch Configuration



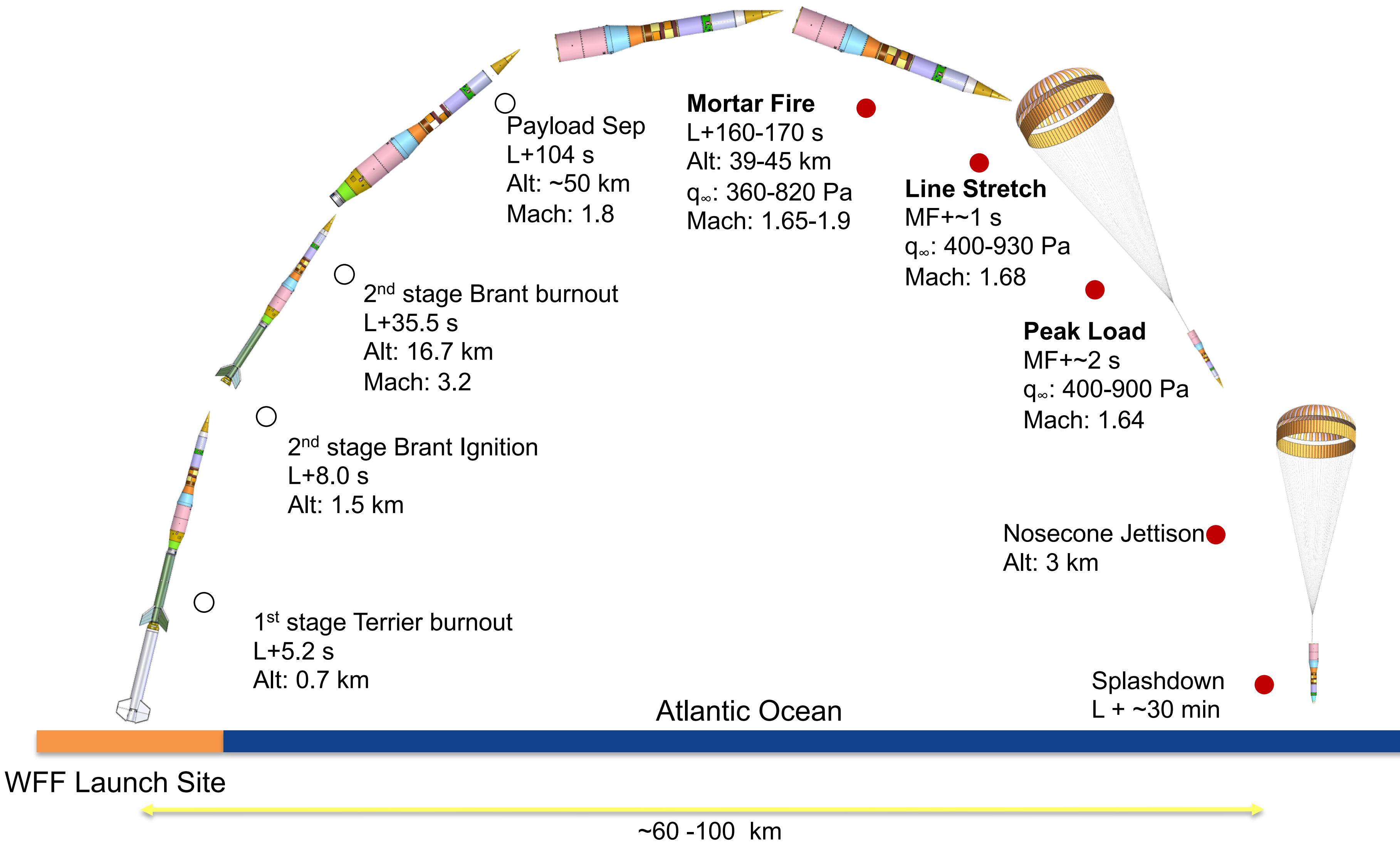
Start of Experiment Phase



Parachute Deployed Configuration



Concept of Operations



Guidance and Control Requirements

ID	Requirement
FP.1	Vehicle will deliver payload to a parachute test condition of between 275 and 1,250 Pa (5.7 and 26.1 psf) while at a velocity of between Mach 1.4 and 2.1 with at least 90% confidence
FP.2	Impact dispersions shall be contained within acceptable range boundaries
GNC.2	Deploy parachute within 5% of desired dynamic pressure with at least 90% confidence. Deploy lens covers and start and stop cameras at appropriate times
GNC.4	Maintain 0 +/- 5 degree angle of attack at the instant of mortar fire with at least 90% confidence
GNC.5	Maintain body rates of < 5 deg/sec about all three axes at the instant of parachute deployment with at least 90% confidence
GNC-1	The experiment shall have a pull angle @ chute full inflation of less than 10 degrees with respect to the velocity vector with a likelihood of 90%

- Monte Carlo simulations used to show compliance with requirements

Why is attitude control system needed?

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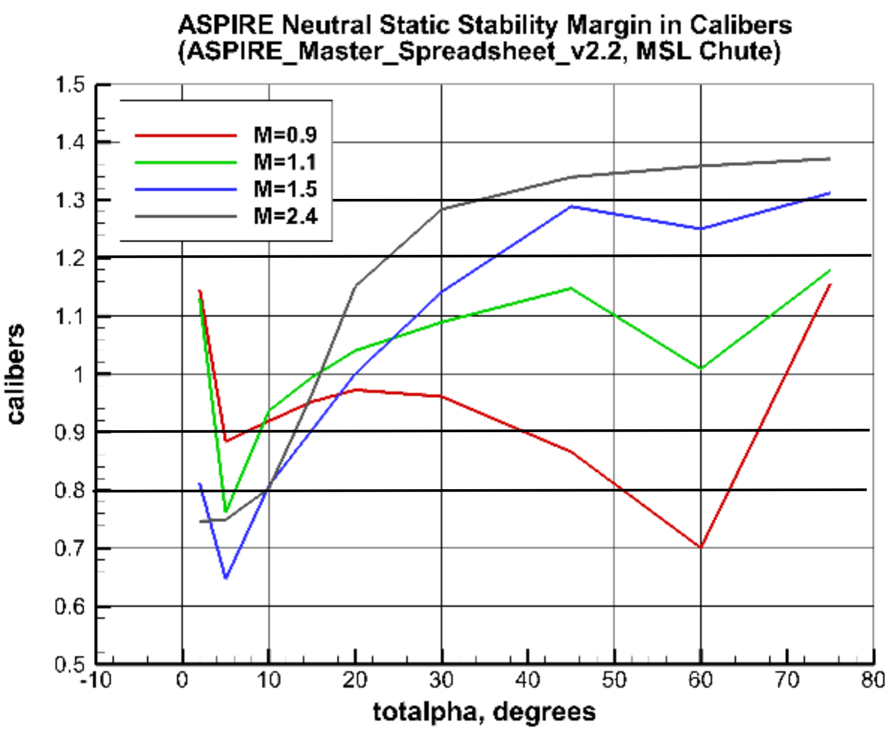
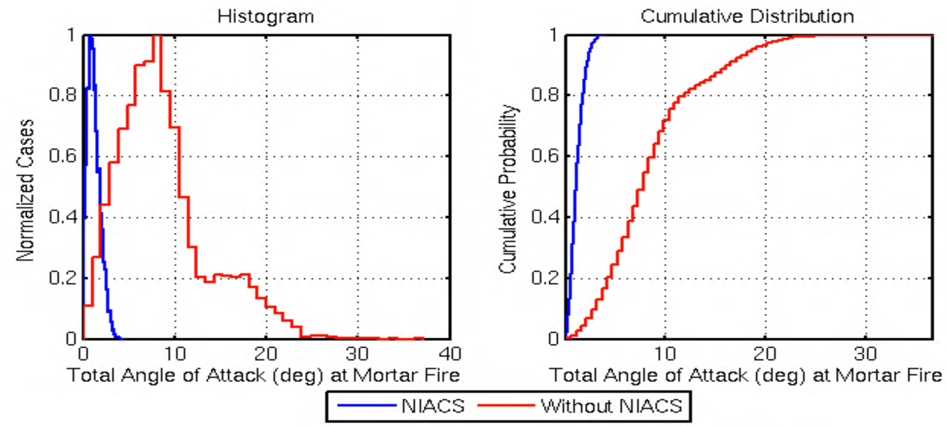
- Vehicle is stable but exhibits large oscillations that violates the angle of attack requirement at mortar fire
- ACS needed to meet pointing requirements





Statistics for:	NIACS	Without NIACS
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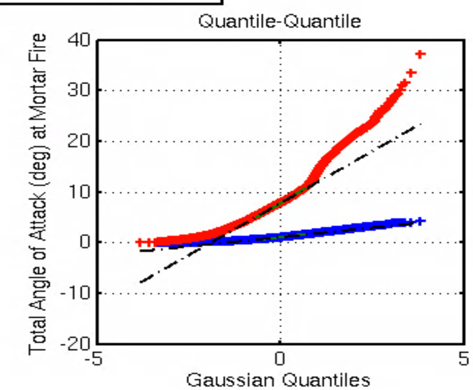
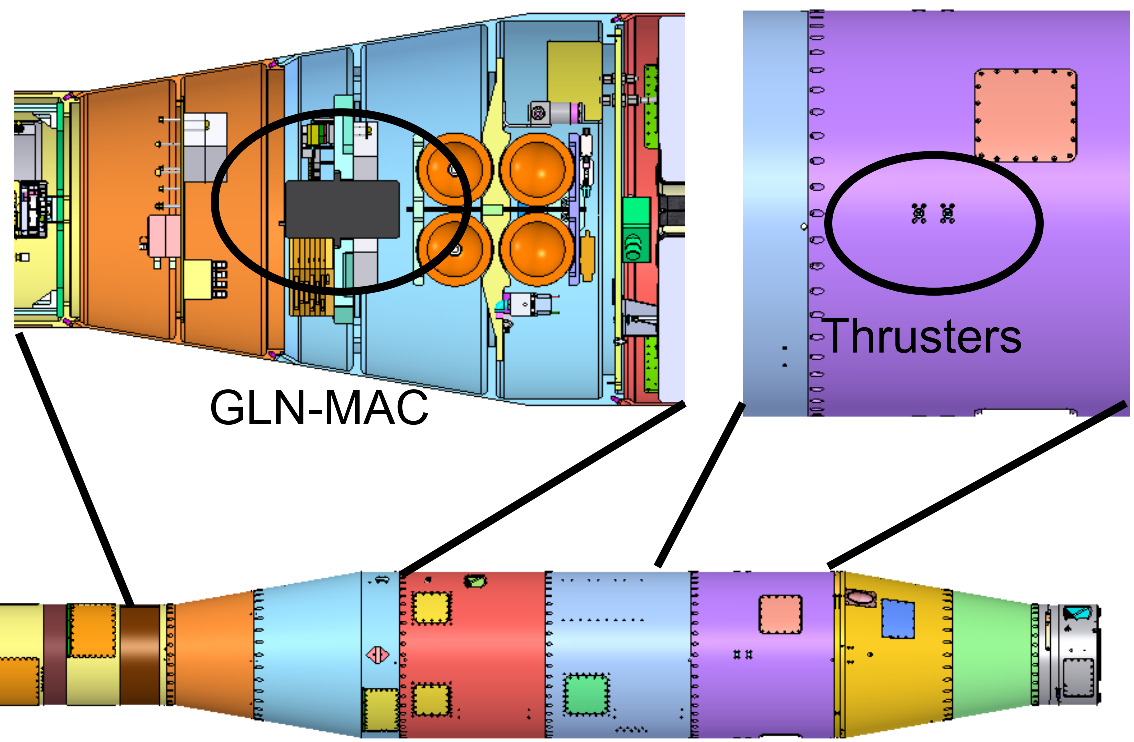
Nominal =	0.8416	9.1936
Mean =	1.2443	8.7734
3-Sigma =	2.0908	14.9639
Minimum =	0.0266	0.0887
1.00 %-tile =	0.1335	0.9951
5.00 %-tile =	0.2920	2.2415
10.00 %-tile =	0.4157	3.2393
50.00 %-tile =	1.1316	7.8869
90.00 %-tile =	2.2306	16.5324
95.00 %-tile =	2.5381	18.9199
99.00 %-tile =	3.1443	22.6797
Maximum =	4.1499	37.0603
Num Cases =	8001	8001



NIACS Overview

- NIACS =
  - NSROC Inertial Attitude Control System
    - NASA Sounding Rocket Operations Contract
      - National Aeronautics and Space Administration

- Off the shelf cold gas attitude control system
- Flown on many missions but only used exo-atmospherically prior to ASPIRE
- GLN-MAC: Gimbaled LN-200 Miniature Airborne Computer



NIACS Overview, continued

- Instrumentation:
  - LN-200 IMU
  - Javad TR-G2 GPS
- Thrusters:
  - Argon gas
  - 4 pairs of pointing thrusters stationed at 90° intervals
    - Control pitch and yaw
  - 2 pairs of clockwise and counter-clockwise roll thrusters
    - Zero out any residual roll rate after booster separation
- ACS active from payload separation to before mortar fire

Flight Software

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- The GLNMAC supplied both trigger AND active vehicle attitude control functions

- Dynamic Pressure Mortar Fire Trigger (1 GLNMAC trigger event on ASPIRE):
  - Free stream q will be estimated by computing **density** and nav velocity + **wind** via **atmosphere polynomials** as a function of altitude

$$\boxed{\text{Estimated } q = 0.5 \times \rho(\text{alt}) \times \text{rvel\_atm}^2(\text{ipos, ivel, Earth\_}\omega\text{, winds(alt)})}$$

- Determined trigger dynamic pressure from desired peak load for parachute test:
  - Calculated using conservation of momentum inside a control volume around the inflating canopy:

$$F_{peak} = k_p(2q_\infty S_p)$$

    - k_p is fraction of the fluid momentum converted to parachute drag
    - S_p is projected area of parachute
    - Determined target dynamic pressure at peak load, q_∞
  - Target dynamic pressure must be mapped to mortar fire
  - Change in dynamic pressure between software mortar fire and full inflation is also sensitive to daily changes in atmosphere
  - Iterative process performed on day prior to launch

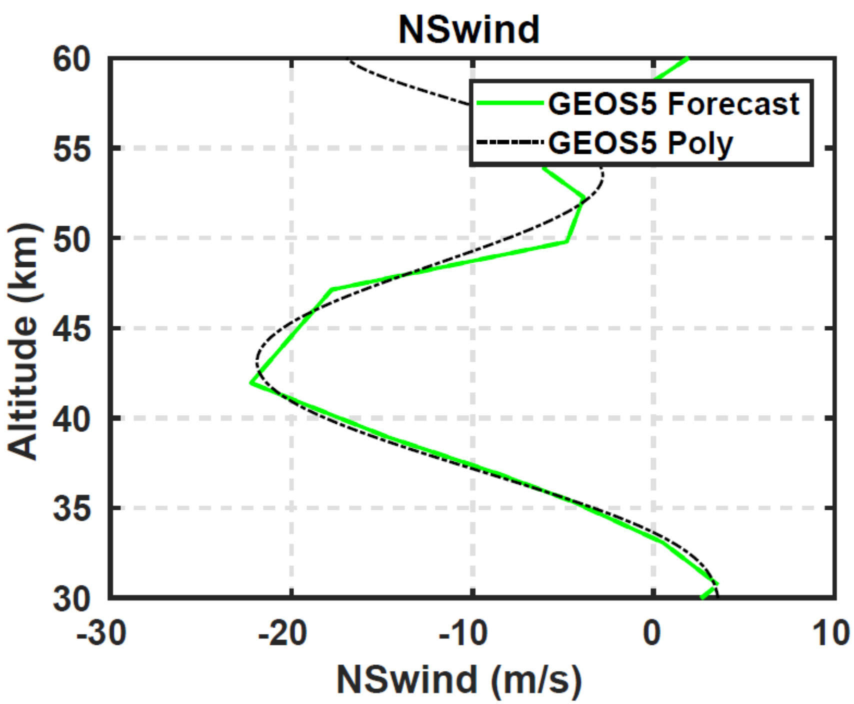
- Trim Attitude Control (NIACS):
  - Atm relative velocity vector utilized in the trigger will also be used as the target vector during attitude control from separation to mortar fire

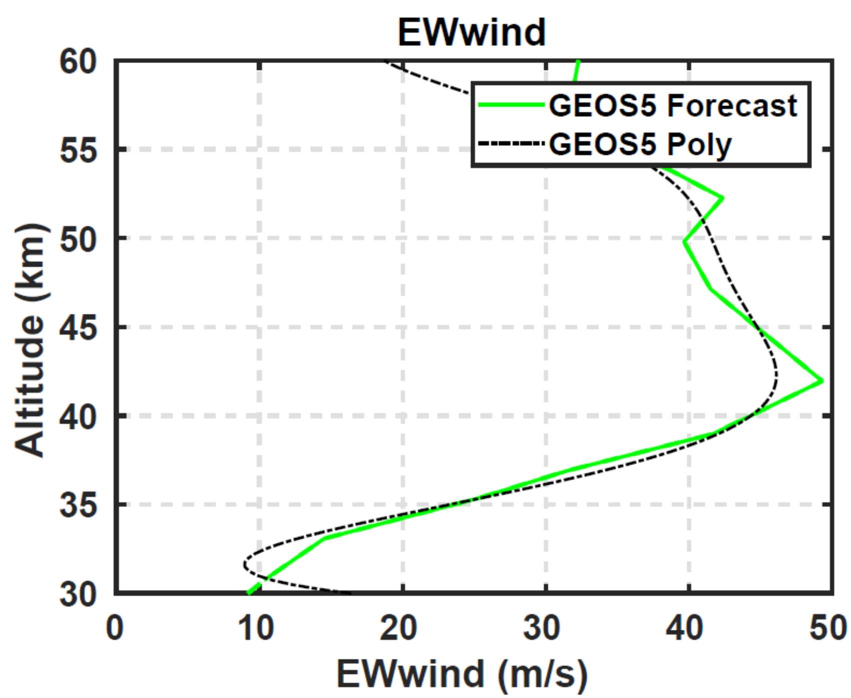
Flight Software Pointing Logic

- Navigation supplied an **inertial velocity** solution which was converted to a **planet relative velocity** by applying Earth rotation
- But trimming involves **atmosphere relative velocity** which involves knowledge of the wind velocity
- Atmosphere relative velocity was necessary given:
  a) The trim condition AoA requirement is <=5deg
  b) The wind at mortar fire can contribute up to ~3deg in AoA
- Wind knowledge provided via the same polynomials used in the triggering logic

Atmosphere Knowledge

- GEOS-5 provided weather forecasts up to 65 km altitude
- Fitted 6th order polynomial for each atmospheric parameter assuming altitude is in 10's of km
  - Mortar fire occurs between 40-45 km altitude
  - Currently fitting from 30-60 km altitude





Flight Results

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- Targeting Performance:

	SR01			SR02			SR03		
	Mach	Trigger q_∞ [Pa]	Peak Load [klbf]	Mach	Trigger q_∞ [Pa]	Peak Load [klbf]	Mach	Trigger q_∞ [Pa]	Peak Load [klbf]
Target	1.7	384	35	1.7	526	47	1.7	780	70
Flight	1.73	400	32.4	1.92	567	55.8	1.81	809	67.4

- Attitude and Rate Performance:

Trigger Conditions	**SR01**	**SR02**	**SR03**
Total Angle of Attack [deg]	0.6	1.3	0.4
Pitch Rate [deg/s]	0.15	-0.1	-0.02
Yaw Rate [deg/s]	0.7	0.6	0.7
Roll Rate [deg/s]	0.15	-0.7	-0.4

SR01 Flight Video

- https://www.youtube.com/watch?v=mTAbj8aRVvg

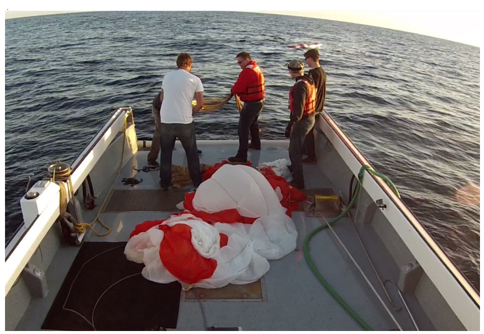
SR02 High Speed Video with Data

ASPIRE Summary Video

- https://www.youtube.com/watch?v=AcAgnQ9K7UY

Conclusions

- All three ASPIRE flights extremely successful
  - Met all success criteria set forth for experiment
- Strengthened parachute design qualified and accepted for Mars flight



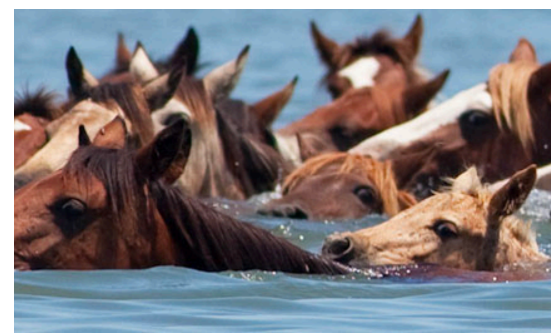


Image: Assateague Island National Seashore

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jpl.nasa.gov

Backup

Test Articles

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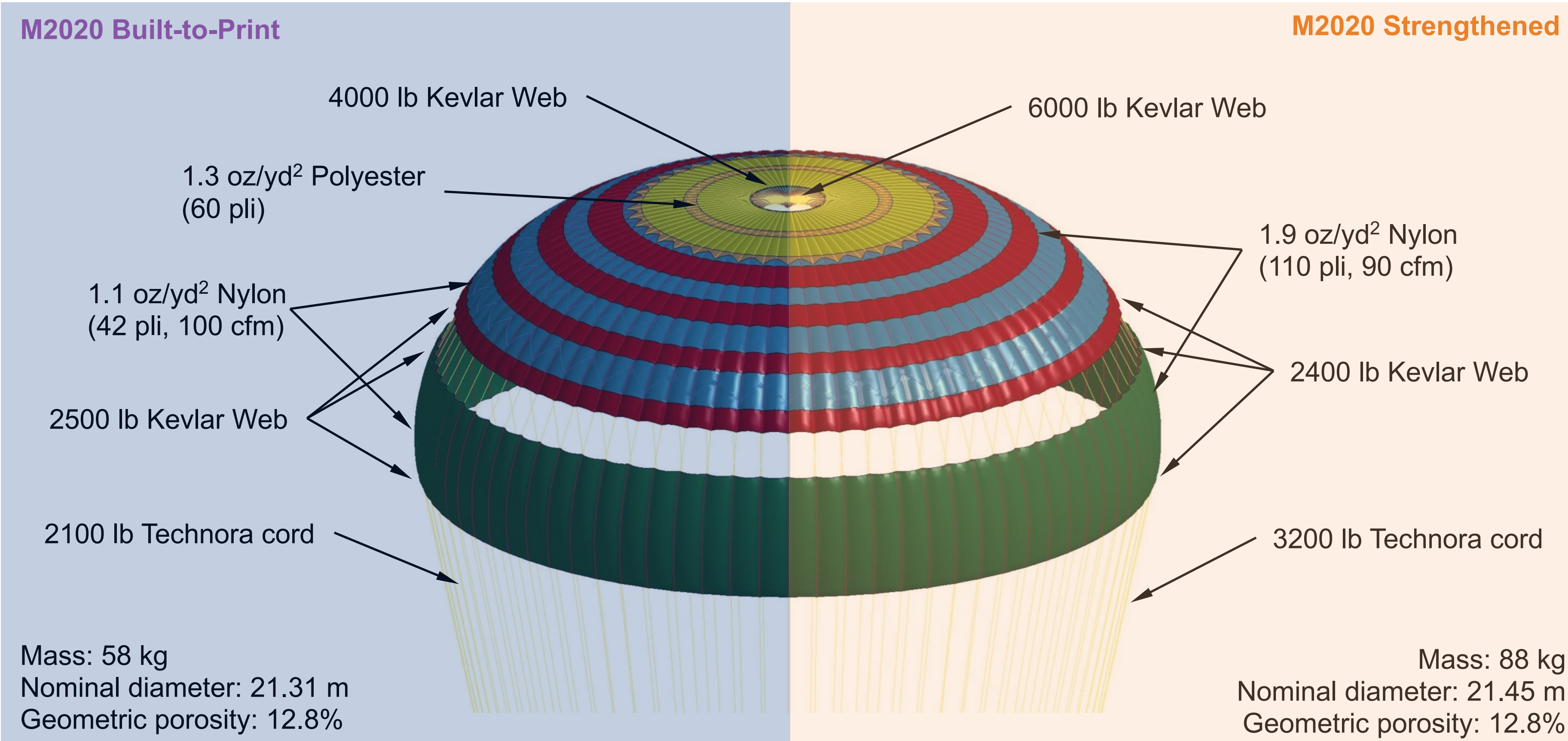
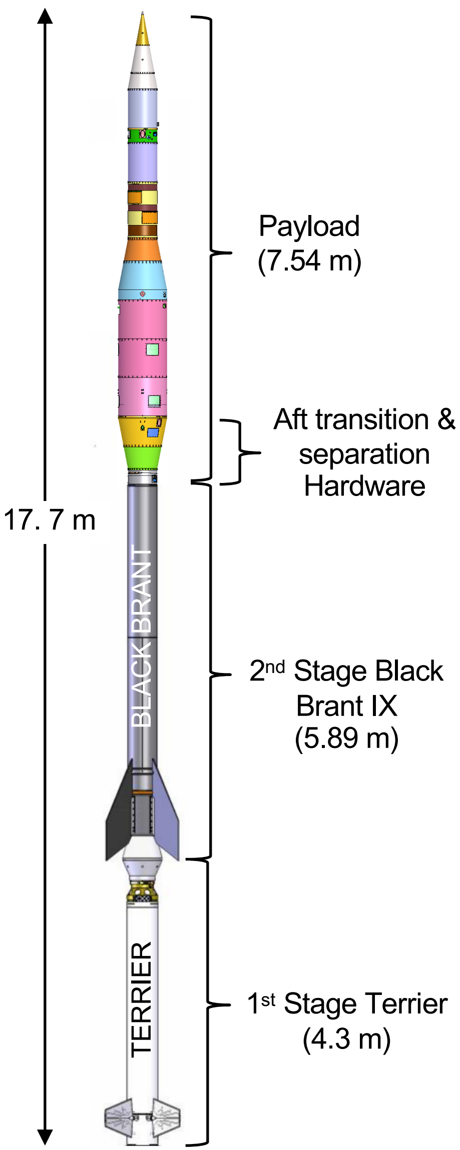
SR01
Target load: 35 klbf

SR02 and SR03
Target load: 47 klbf and 70 klbf



Test Architecture



- Rail-launched Terrier Black Brant
- Spin-stabilized at 4 Hz
- Yo-yo de-spin after 2nd stage burnout
- Mortar-deployed full-scale DGB
- Cold gas ACS active from payload separation to before mortar fire
- Recovery aids:
  - Foam provides buoyancy
  - Nosecone ballast (for additional mass & aerodynamic stability) is jettisoned before splashdown
- Payload mass:
  - Launch: 1268 kg
  - Post-separation: 1157 kg
  - Splashdown: 495 kg